IMPACT OF FRICTION REDUCTION TECHNOLOGIES ON FUEL ECONOMY FOR GROUND VEHICLES

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13 August 2009 UNCLAS: Dist A. Approved for public release

GVSETS

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
08 AUG 2009	**N/A**	**-**

4. TITLE AND SUBTITLE
Impact of Friction Reduction Technologies on Fuel Economy for Ground Vehicles

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
20144 RC

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
TACOM/TARDEC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
20144 RC

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at NDIAs Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), 17 22 August 2009,Troy, Michigan, USA, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**21**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Outline of Presentation

- Overview of Petroleum Consumption - How Much Do We Actually Use
- How Does Tribology (Friction and Wear) Fit Into the Equation
  - If we get rid of all friction, how big of an impact will a ‘frictionless’ engine have on petroleum consumption
  - If We reduce friction by x%, how much petroleum can we save?
- What’s the Difference Between Commercial and Military Applications
  - Driving/Operational Driving Schedules
- What’s Being Done (Research) to Reduce Petroleum Consumption, or, Improve Energy Security?

World Energy Production & Consumption
1 QUAD/yr ~ 0.5 MBBL/day

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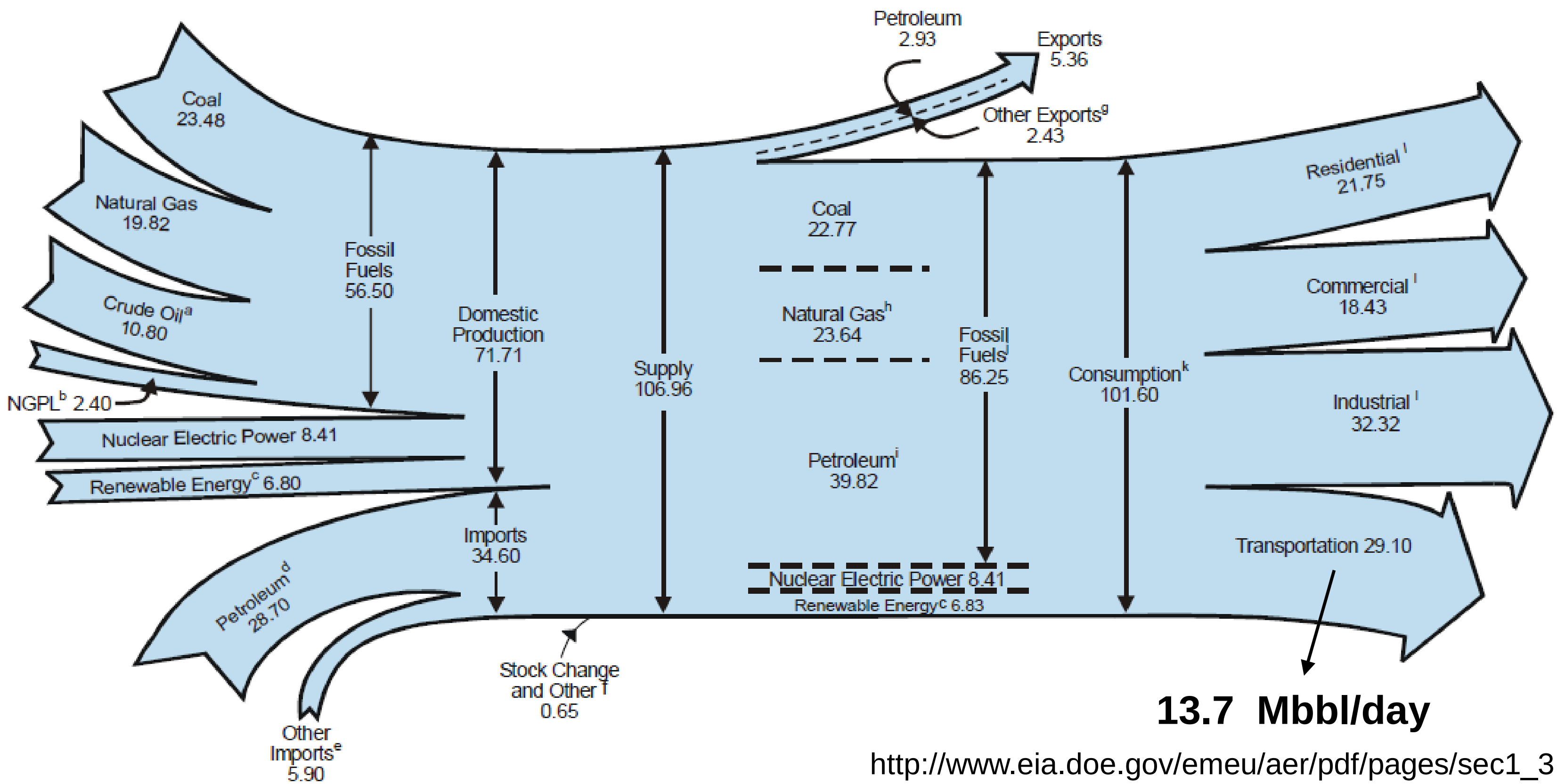
• World Energy **Production** (All Sources)	460 Quads (2005)
• US Energy **Production** (All Sources)	72 Quads (2007)
– 16% of World Production	
• World Energy **Consumption** (all sectors)	463 Quads (2005)
• US Energy **Consumption** (all sectors)	101 Quads (2007)
– 22% of World Consumption	
• World Petroleum **Production**	81 MBBL/day (2007)
• US Petroleum **Production**	6.9 MBBL/day (2007)
– <9% of World Production	
• World Petroleum **Consumption** (all uses)	85 MBBL/day (2006)
• US Petroleum **Consumption**	21 MBBL/day (2006)
– 25% of World Consumption	

http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf

US Energy Flow (2007)
102 QUADs



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_3.pdf

- QUADrillion (10^{15}) BTUs per year
- 1 QUAD equivalent to 0.47 million bbl crude oil/day
  - 39.82 QUAD Petroleum - 18 million bbl/day

Majority of Oil Consumed by ON-ROAD Vehicles - 10 to 11 MBBL/Day for Cars, Light Trucks, and Heavy Trucks

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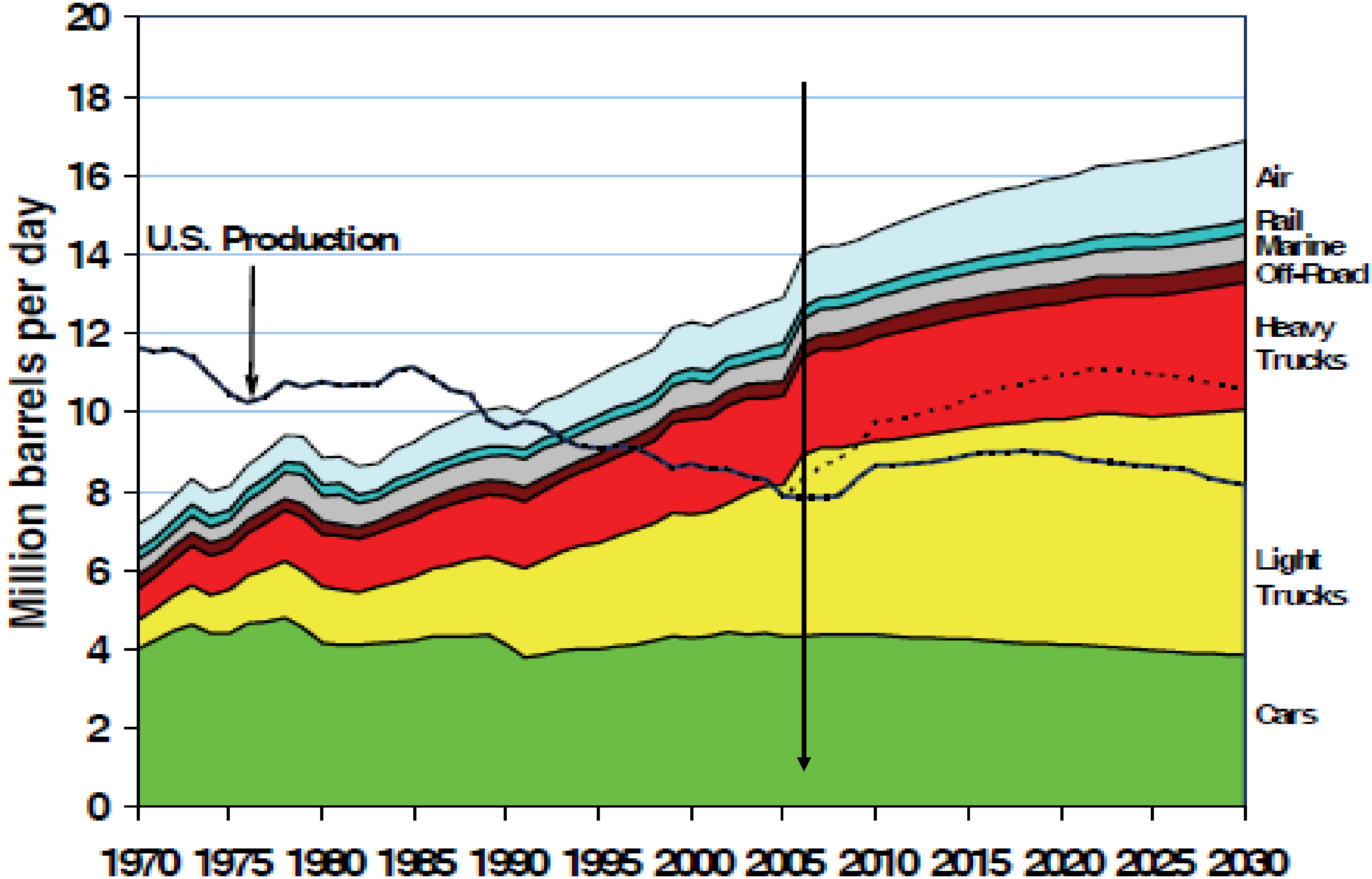


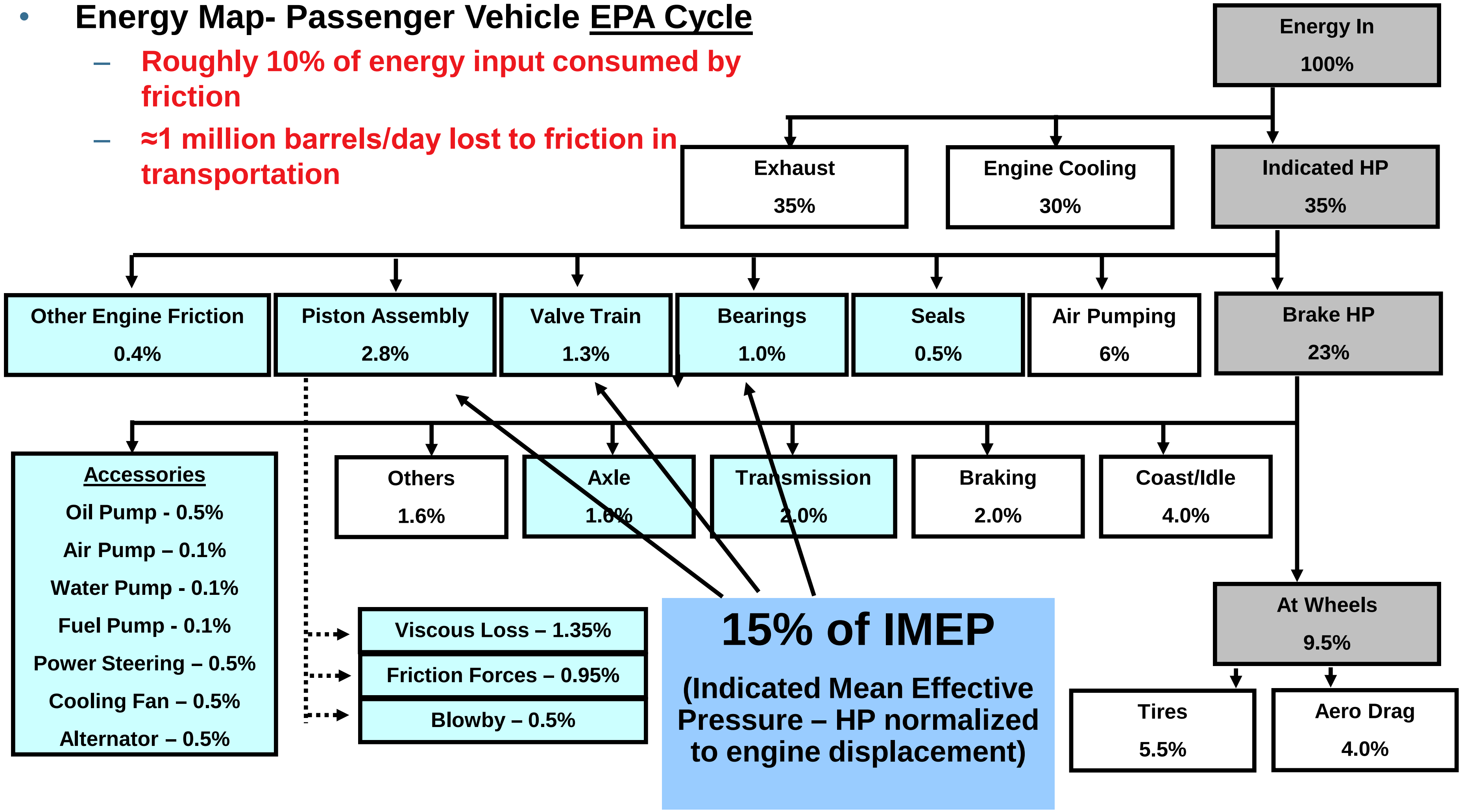
Federal Government is Largest Single Consumer of Petroleum

- In FY 2004; federal agencies accounted for 1.9 % of US petroleum consumption
  - DoD - 93% of US Government Consumption
  - DoD - equivalent to 360,000 bbl/day

- Cost of Petroleum
  - Commercial/civilian (large volume/low price)
    - $50 to $ 150/bbl
    - $2.00-$4.50/gal at pump
  - Military (lower volume / high price)
    - $50 to $150/bbl
    - $20-$30/gal delivered (aircraft)
    - $100-$600/gal delivered in field (ground vehicles)

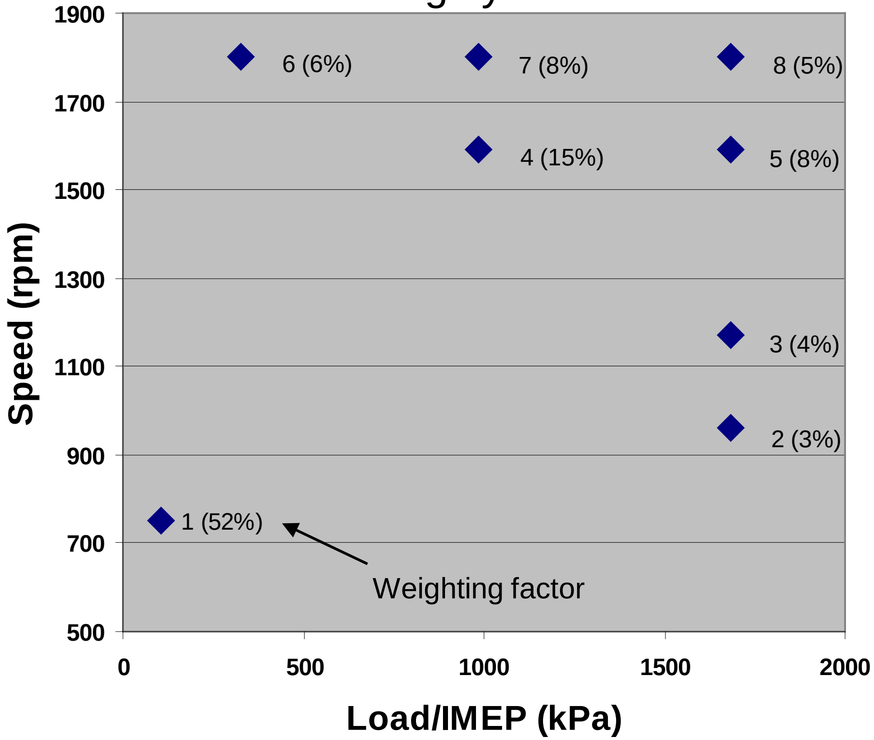
How Much of the 10-11 MBBL/day of Petroleum Used for On-Road Vehicles is Lost to Friction? - More Energy is Lost to Friction Than is Delivered to the Wheels

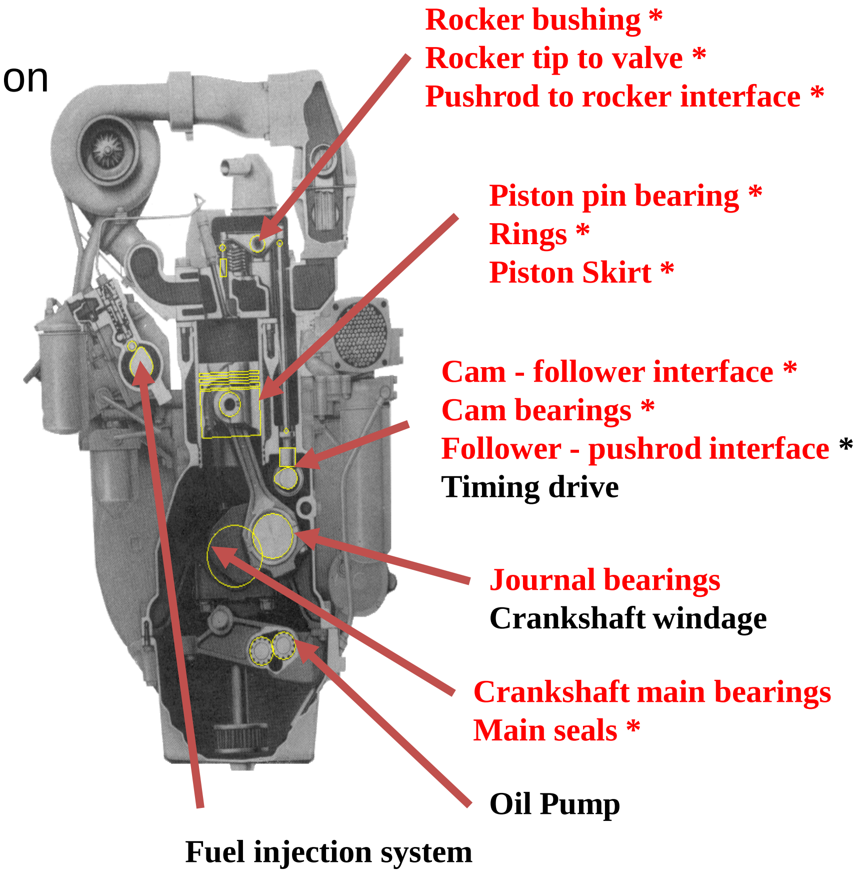
- **Energy Map- Passenger Vehicle EPA Cycle**
  - **Roughly 10% of energy input consumed by friction**
  - **≈1 million barrels/day lost to friction in transportation**



Detailed Studies of Heavy-Truck Friction Losses Based on Mechanistic Models of Boundary and Hydrodynamic Friction Predicted Impact of Lowering Boundary Friction and Lubricant Viscosity on Fuel Economy

- FMEP calculated at 8 different modes and weighted to predict effect on fuel consumption for a HD driving cycle



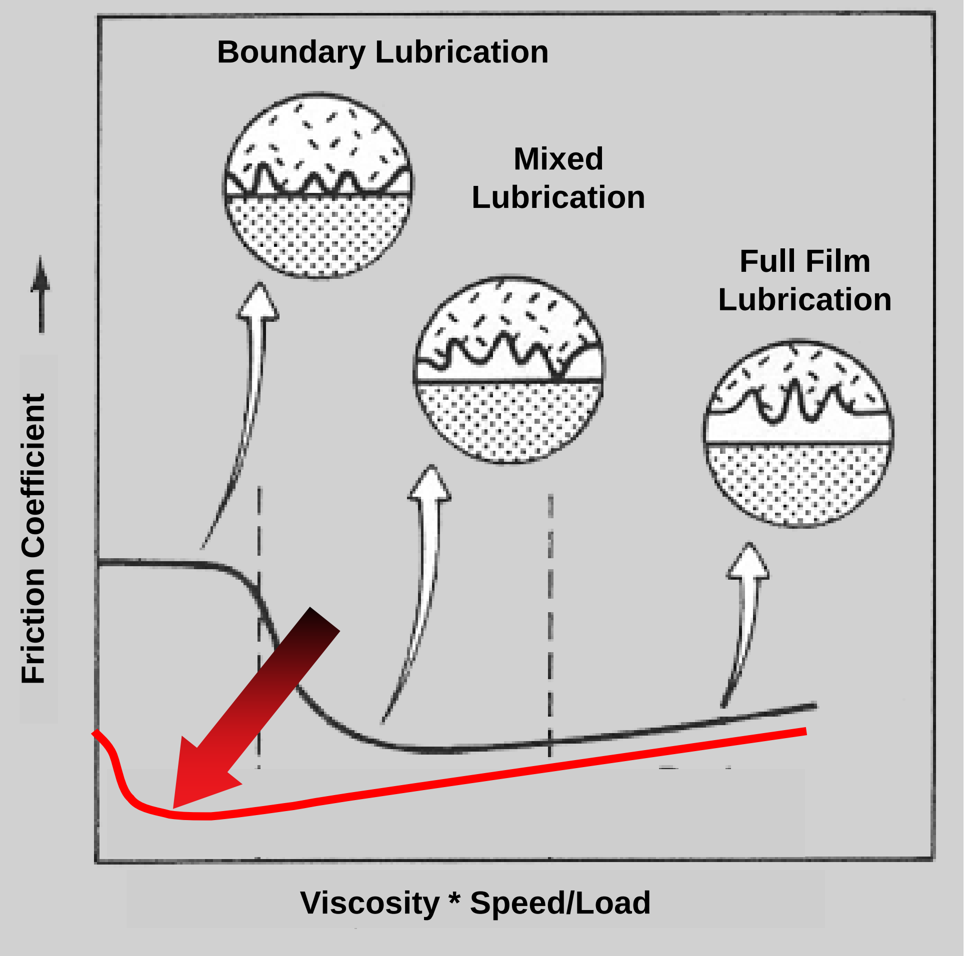


* interface considered in current study

$$\text{FCSF (Fuel Consumption Scaling Factor)} = \frac{\text{IMEP} + \Delta\text{FMEP}}{\text{IMEP}}$$

Role of Boundary and Hydrodynamic Lubrication Regimes - Tribological System

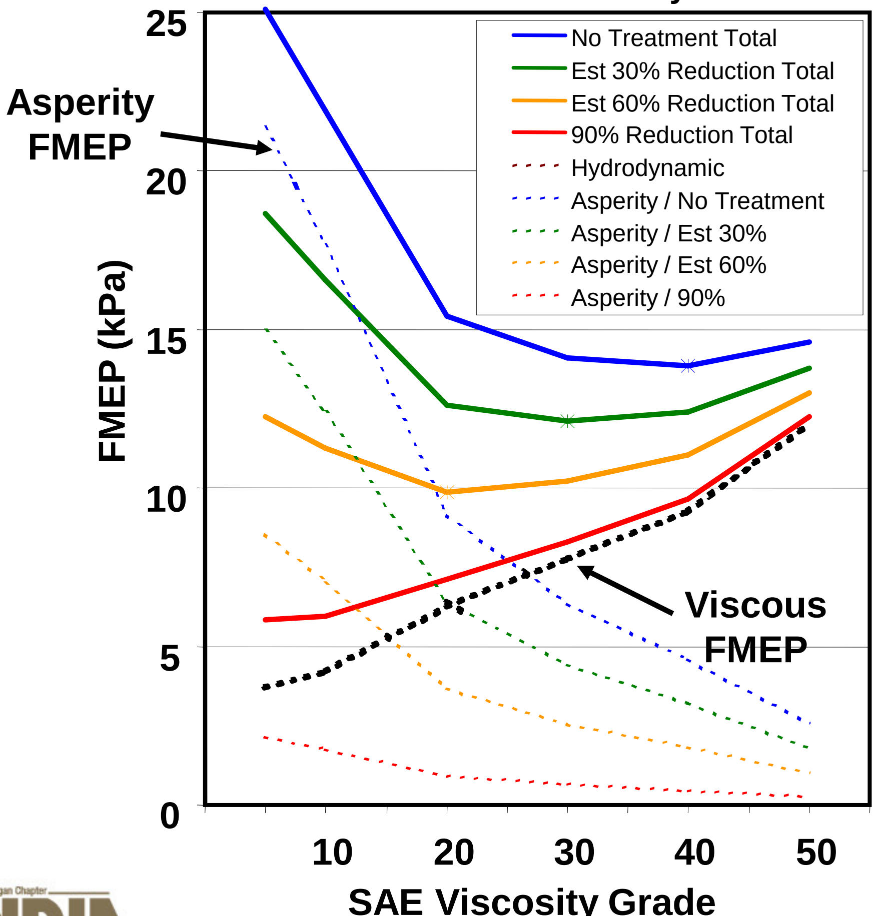
- Different regimes of lubrication depending on the degree of contact between sliding surfaces
- Boundary lubrication characterized by solid-solid contact – asperities of mating surfaces in contact with one another
- Contrast boundary lubrication with full-film lubrication in which mating surfaces are separated by a film.
- In between, mixed lubrication occurs.



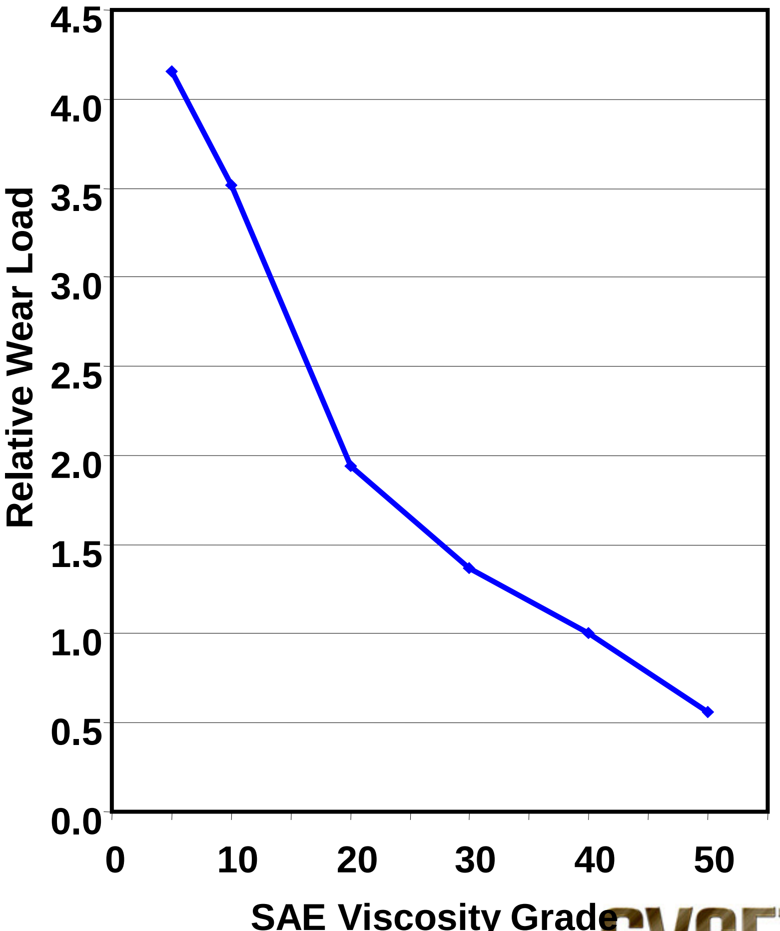
Boundary and Hydrodynamic Friction: Model Impact on FMEP and Wear Severity

- Total FMEP is the sum of the Asperity friction and the hydrodynamic friction
  - Boundary FMEP decreases with increasing lubricant viscosity – shifting from BL to ML regime
  - Hydrodynamic FMEP increases with increasing viscosity

Piston FMEP versus Viscosity Grade

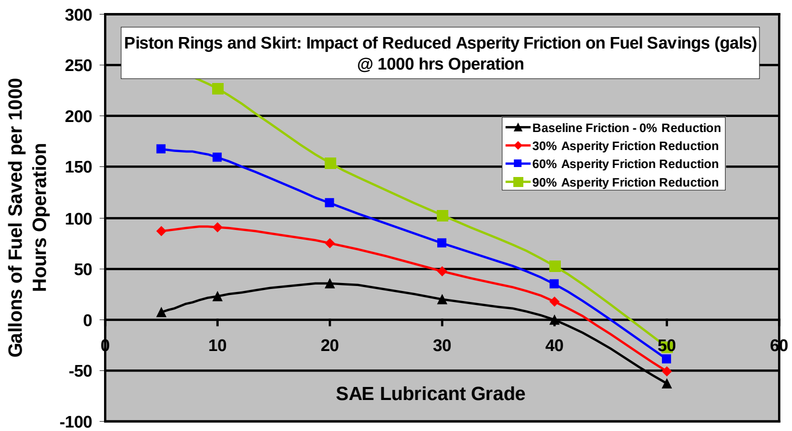


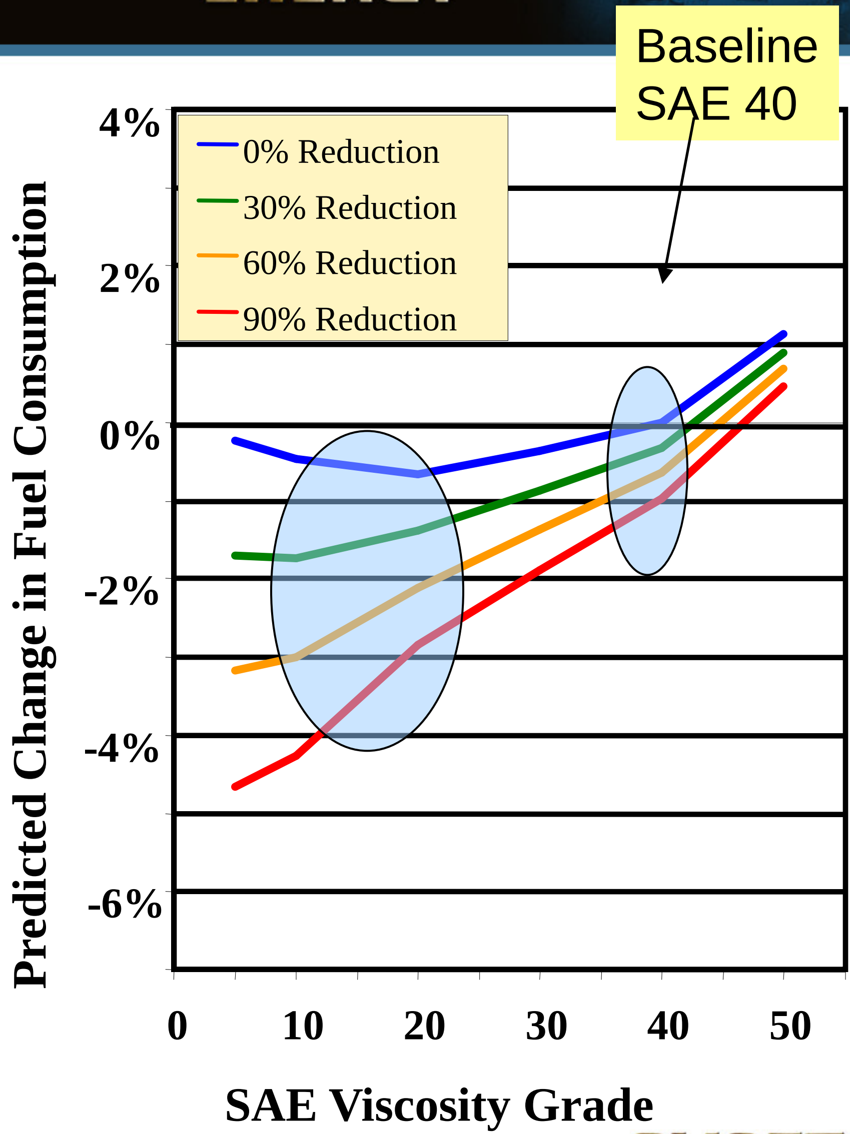
Normalized Piston - Liner Contact Severity



Prediction/Modeling of Fuel Savings

- Systematic studies on the effect of boundary friction and oil viscosity on fuel efficiency
- **Up to 1.3 % fuel economy improvement** by low friction additives and/or coatings
- **3-4% fuel economy improvement** by reducing boundary friction and reducing oil viscosity
- Additional 2-4% fuel economy gains in transmission and differential/axle





'HOWEVER, ... Your mileage may vary…'

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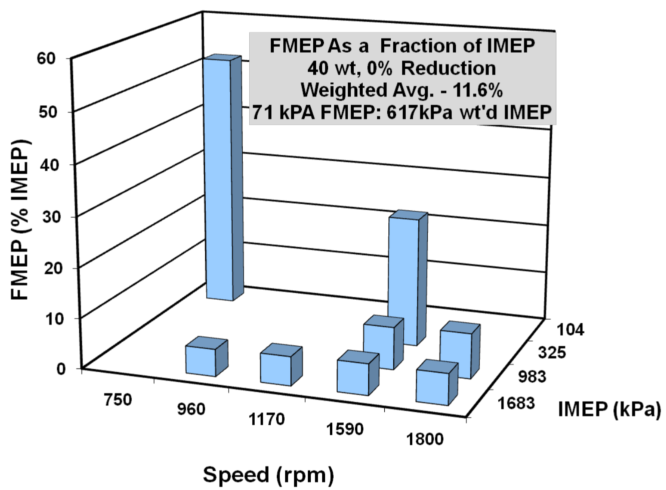
- Standard disclaimer '**Your mileage may vary'** on EPA mileage estimates is used for a very valid reason, and this is especially true for estimating the impact of friction on the fuel efficiency of military vehicles
  - Parasitic frictional losses depend strongly on engine conditions (load and speed). Highest losses (percentage of IMEP) occur at low speed, low load conditions



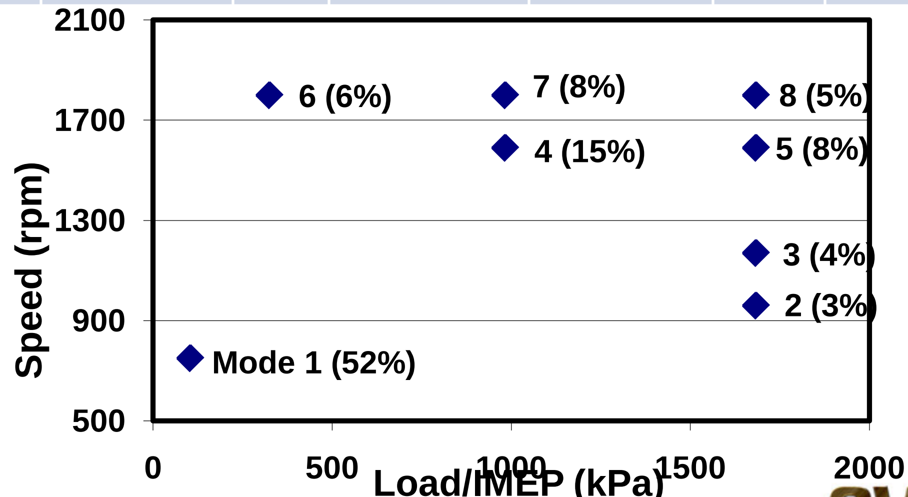
- There are significant differences between civilian on-road driving cycles and military driving cycles
  - High percentage of time spent near idle
  - Off-road (high load) and low speed conditions

Military Driving Cycle Significantly Different from On-Road Civilian Cycle

- Wheeled Ground Vehicle (80-85 % idle; 25 mph avg.)

Patterns of Use				M998 Baseline			M998 w Armor; w A/C		
	Time (hr)	Distance (mi)	<speed> mph	Burn Rate (gal/hr)	mpg	Consumed (gal)	Burn Rate (gal/hr)	mpg	Consumed (gal)
Total Mission	24	100	25/0	1.4	6.8	32.6	1.9	5.3	46.0
Primary Rds	0.6	20	33	3.3	10.6	1.9	4.2	8.4	2.4
Secondary Rds	1.7	50	30	3.4	8.8	5.7	4.2	7.2	7.0
Trails	0.8	20	25	4.8	5.2	3.9	6.5	3.8	5.2
Cross-Country	1	10	10	3.2	3.1	3.2	4.2	2.4	4.2
Idle	20	-	-	0.9	-	18.0	1.4	-	27.2

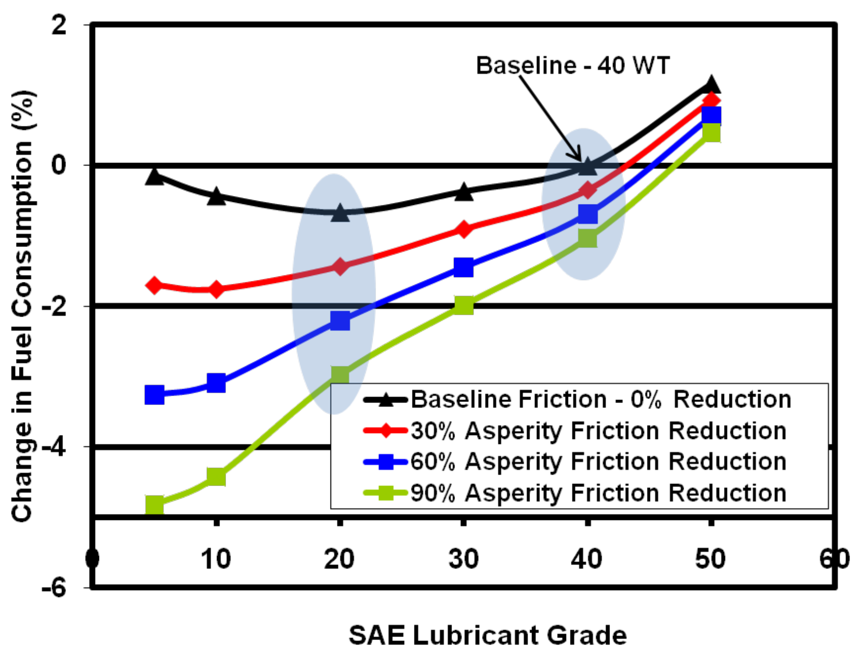
- On-Road FTP
  - Low idle
  - High speed
  - On-road (low load)



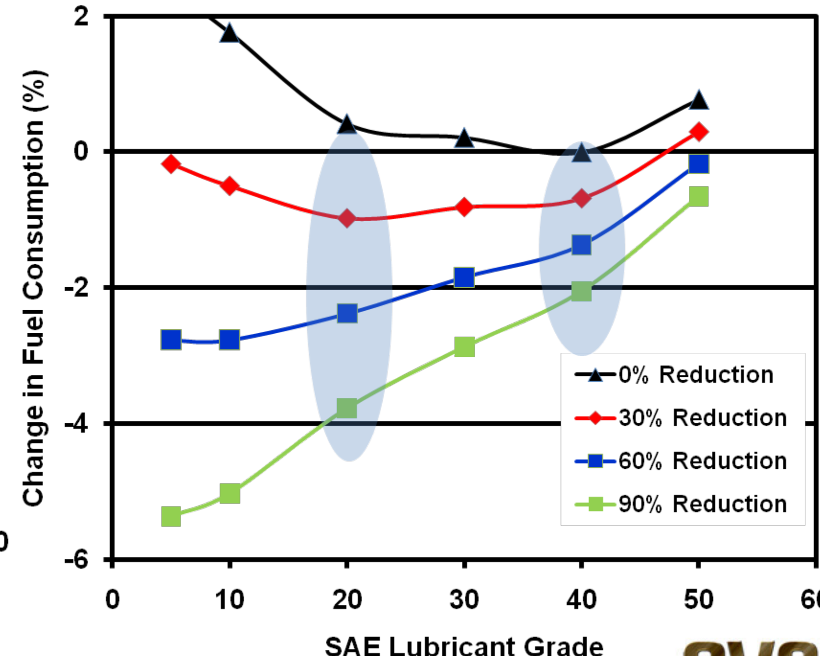
MITRE Corporation, Report No. JSR-06-135

- Low friction technologies at high Idle, low speed, high load conditions (lower right) have greater impact on fuel consumption

On-Road FTP

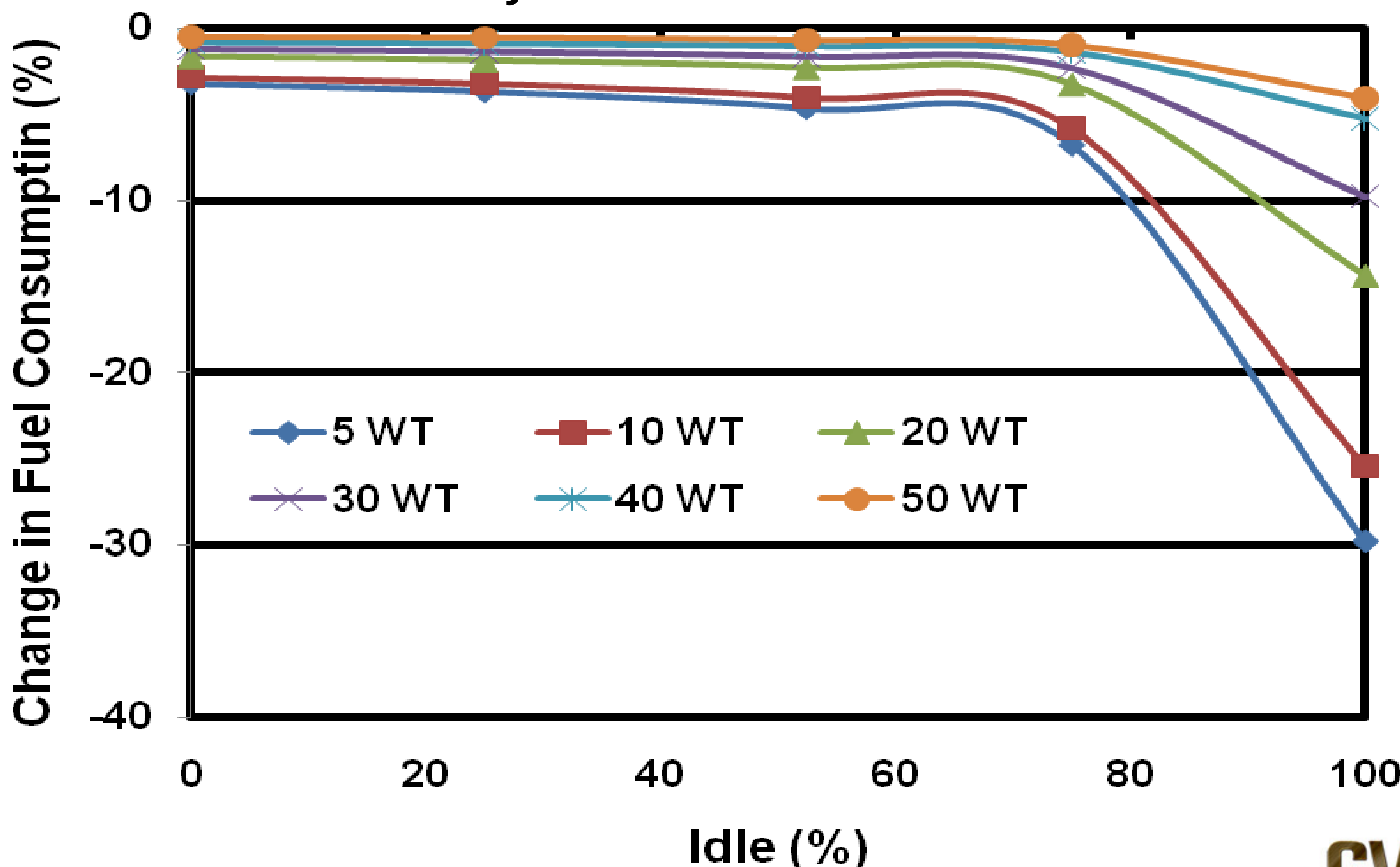


70 % Idle, Mode 2 & 3



Friction Reduction Technologies Have Greater Impact on Fuel Economy at High Idle Conditions

- Impact of Idle on the fuel consumption for a 90 % reduction in boundary friction



Fuel Efficiency - Summary

- 13-14 Mbbl/day consumed for transportation
- US military consumes 2% - approx 360,000 bbl/day
  - Cost of fuel delivered to theatre is high ($100-$600/gal)

- Rule-of-Thumb
  - Approx 10% of fuel consumed (on-road) is lost to engine friction
  - Another 5% lost to driveline friction

- Driving cycle significantly impacts the efficacy of low-friction technologies to improve fuel economy
  - High idle modes are impacted more by low-friction technologies

Additional Comments – Viscosity & Durability

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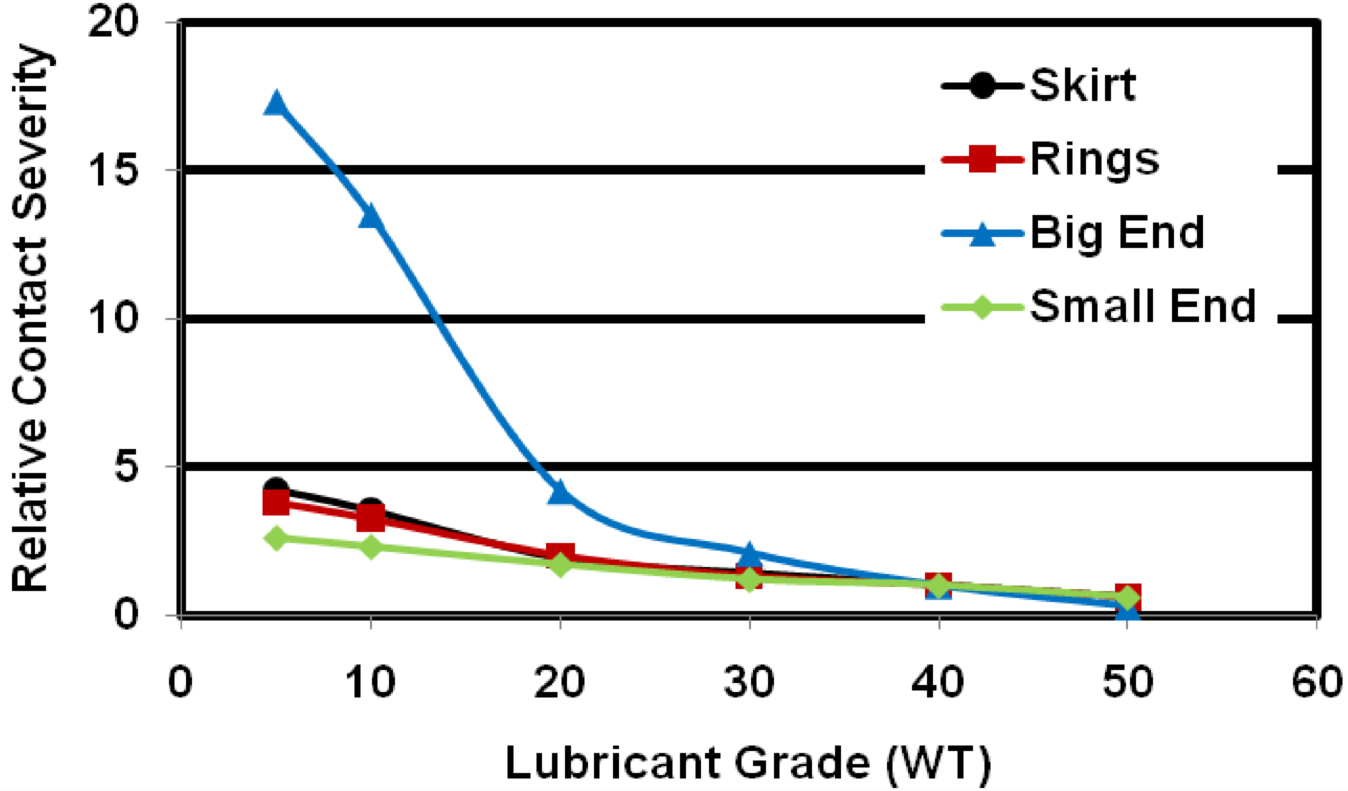
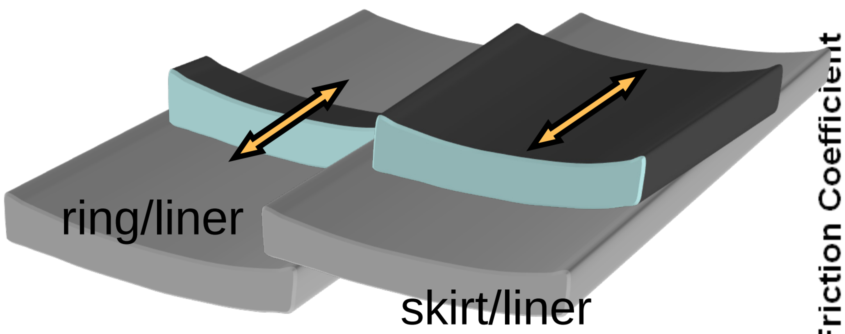
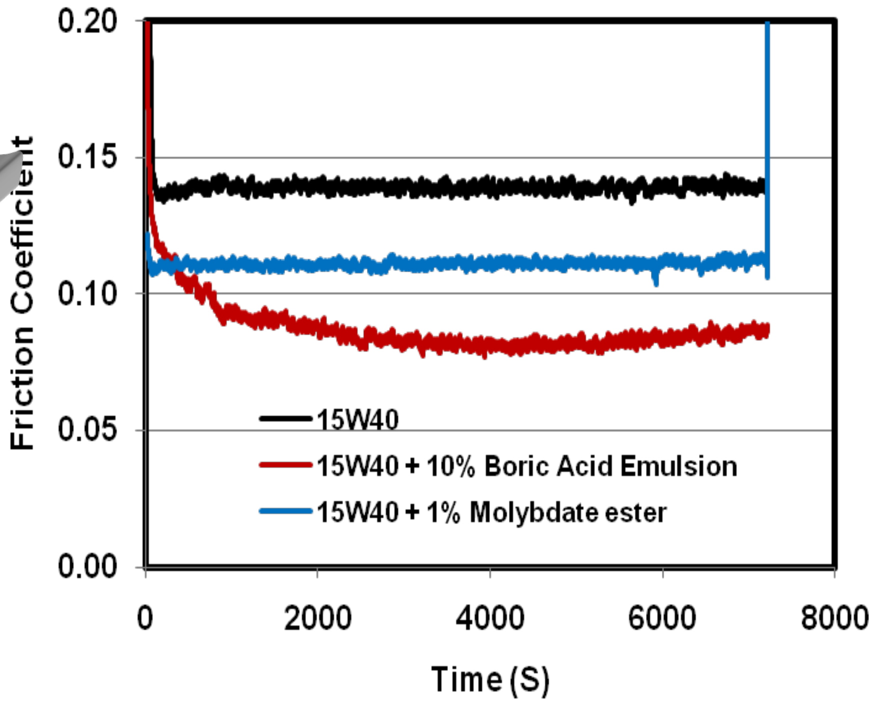
- Use of low-viscosity lubricants, while effective in reducing fuel consumption, will increase contact severity
  - Need for improved wear-resistant materials, coatings and anti-wear additives

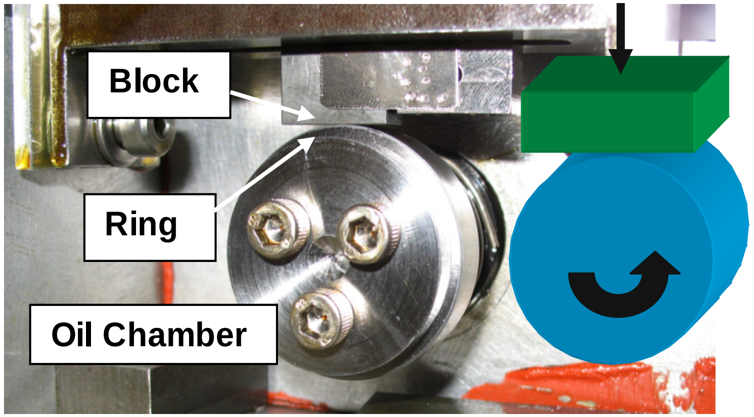


- Multiple approaches to reduce friction – materials, coatings, additives – requires lab, component, and system testing.

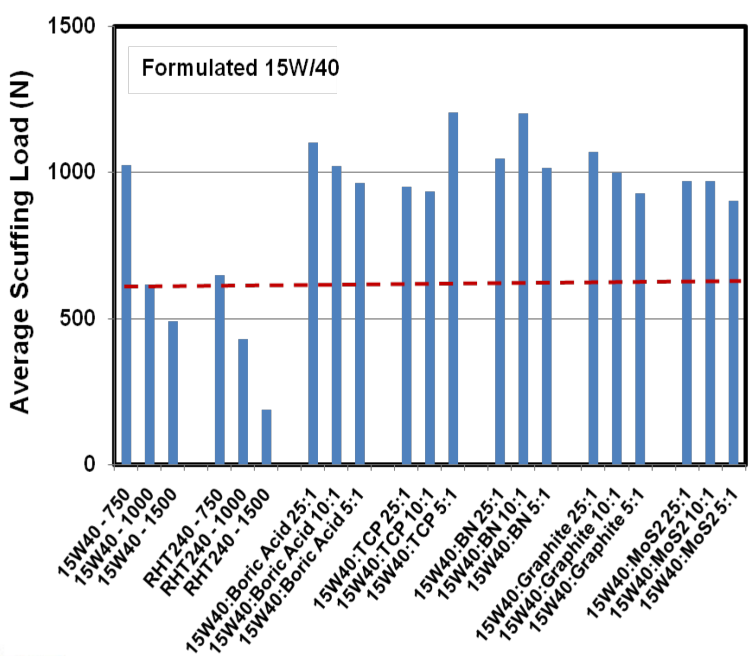


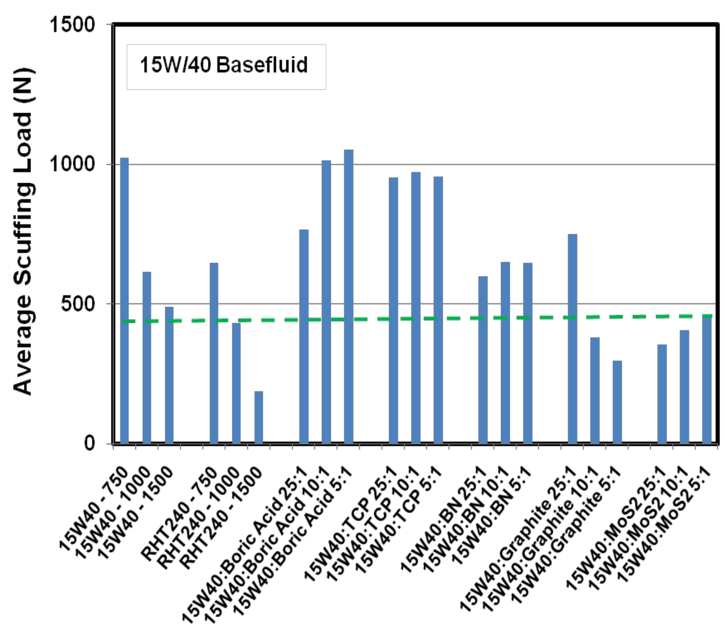


- Application of advanced lab techniques to characterize scuffing phenomena and investigate the impact of additives on delaying the onset of scuffing.



- Impact of additives and additive concentration on the scuffing load of formulated mil-spec 15W/40 oil, and unformulated basefluid





Conclusions

- Parasitic friction mechanisms (oil shearing and metal-to-metal asperity friction) consume approximately 10% of fuel used in transportation. Another 5% is consumed by drivetrain friction.
- The losses can be significantly greater for vehicle operating cycles that involve long periods of idle, where power is required for hotel power.
- Application of low-friction boundary-film technologies will lower fuel consumption by 1% for an on-highway commercial truck. Greater fuel savings (up to 2%) can be realized for high-idle driving cycles that involve off-road conditions.
- The application of low-friction technologies that lower friction in the boundary-lubrication regime (Stribeck curve) enables the use of low-viscosity fluids resulting in potential fuel savings up to 3-4% for commercial driving cycles – provided suitable low-friction technologies are available.
- While low-viscosity lubricants are beneficial in reducing parasitic friction losses, caution must be exercised to offset the increased contact severity and potential durability/reliability issues associated with increased contact loads that occur with low-viscosity fluids.
- Potential solutions to improve fuel economy, such as lubricant additives and low-friction materials/coatings, have been identified in lab studies, and need further effort to implement them industrially.
- The use of advanced additives in formulated mil-spec lubricants has been observed to increase the scuffing resistance in lab-based tests and may represent a potential solution to enhancing the survivability of ground vehicles under extreme tribological environments.
- **High idle drive cycles incur the greatest amount of parasitic friction losses and are influenced more by low-friction technologies**